Transportation Research Interdisciplinary Perspectives 20 (2023) 100845

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.elsevier.com/locate/trip

An AV-MV negotiation method based on synchronous prompt information on a multi-vehicle bottleneck road

Yang Li [a,*], Hao Cheng [b], Zhe Zeng [c], Barbara Deml [a], Hailong Liu [d]

[a] Institute of Human and Industrial Engineering, Karlsruhe Institute of Technology, Engler-Bunte-Ring 4, Karlsruhe, 76133, Germany
[b] Institute of Cartography and Geoinformatics, Leibniz University Hannover, Appelstr. 9A, Hannover, 30167, Germany
[c] Human Factors, Institute of Psychology and Education, Ulm University, Albert-Einstein-Allee 45, Ulm, 89081, Germany
[d] Graduate School of Science and Technology, Nara Institute of Science and Technology, 8916-5 Takayama-cho, Ikoma, Nara, 630-0192, Japan

ARTICLE INFO

Keywords:
Automated vehicle
Human-AV communication
External human–machine interface (eHMI)
Internal human–machine interface (iHMI)
Bottleneck road
Traffic psychology

ABSTRACT

Bottleneck roads with narrowed width often only allow one vehicle to pass at once. In this situation, human drivers need to negotiate their right-of-way via, e.g., hand gestures and eye contact. However, when a human-driven vehicle (MV) confronts a driver-less automated vehicle (AV), explicit communication between drivers is no longer possible. External human–machine interfaces (eHMIs) on AVs may facilitate communication in unobscured situations, but MV-drivers can fail to perceive the eHMI information on the AV with other vehicles in front of the AV, blocking the MV's view. Even if the visibility is not impaired, AV broadcast communications do not target on specific receivers, it is not unlikely that other vehicles may wrongly perceive this information. Instead, an internal human–machine interface (iHMI) can uni-cast the AV intention to MVs since the information on iHMIs is direct to MV-drivers and visible in visibility-blocked situations. However, iHMIs require vehicle-to-vehicle communication technology, and the conveyed information might not be highly trusted as the information is transmitted to MVs rather than being seen directly from AVs. Therefore, this paper proposes a synchronous iHMI+eHMI method for a more unambiguous communication in this multi-vehicle bottleneck road situation. The designed *iHMI+eHMI* is compared with the baseline i. e., *without HMI*, *iHMI*, and *eHMI* in a video-based driving simulation by subjective evaluations from structured questionnaires. The results (N=24) indicate that HMIs (*iHMI*, *eHMI*, and *iHMI+eHMI*) are more helpful than vehicles without any HMI for the AV-MV communication, and *iHMI+eHMI* achieves the best performance when the views of MV-drivers are obscured.

1. Introduction

In the foreseeable future, we will be witnessing a revolution in mobility, e.g., level 4 and 5 automated vehicles (AVs) (SAE International, 2021) integrating into urban areas rapidly (Kersten et al., 2021). Highly automated mobility is claimed to have the potential to support human drivers and reduce injuries, crashes, and economic tolls caused by human errors (NTHSA, 2020). The advent and popularity of AVs will let them directly interact with human road users, such as manually driven vehicles (MVs), pedestrians, and cyclists. This direct interaction inevitably causes many concerns about traffic safety as AVs behave differently to MVs (Färber, 2016). To improve the sense of relief and trust in AVs, they should be able to interact and communicate their driving intentions unambiguously and comprehensibly with other human road users (Fuest et al., 2017; Schieben et al., 2019; Liu et al., 2021). However, establishing good communication between AVs and other human road users is very challenging in mixed traffic, especially in ambiguous right-of-way use cases when negotiations are needed, such as on bottleneck roads (Miller et al., 2022), at intersections (Papakostopoulos et al., 2021), or for lane changing and merging (Kauffmann et al., 2017). This is because (1) AVs lack explicit information from drivers when they are not involved in driving tasks (Fuest et al., 2017), (2) inattentive drivers and passengers in the AVs may lead to unconscious hand gestures and eye contact that could imply misdirection (Färber, 2016), and (3) the AVs' kinematics may differ from MVs' (Fuest et al., 2020) and consequently cause misunderstanding for the other human road users. These insufficient or erroneous AV-MV communications can increase hesitation in yielding or taking right-of-way (Liu et al., 2021) and reduce traffic efficiency (Rettenmaier and Bengler, 2020). In worse cases, it may even result in MV-drivers' uncertain feelings about AV movements (Färber, 2016), a decreased sense of safety (Kaparias et al., 2015; Liu et al., 2021), and lowered trust (Hoff and Bashir, 2015; Liu et al., 2021) in AVs.

* Corresponding author.
E-mail address: yang.li@kit.edu (Y. Li).

https://doi.org/10.1016/j.trip.2023.100845
Received 27 September 2022; Received in revised form 21 April 2023; Accepted 17 May 2023
Available online 29 May 2023

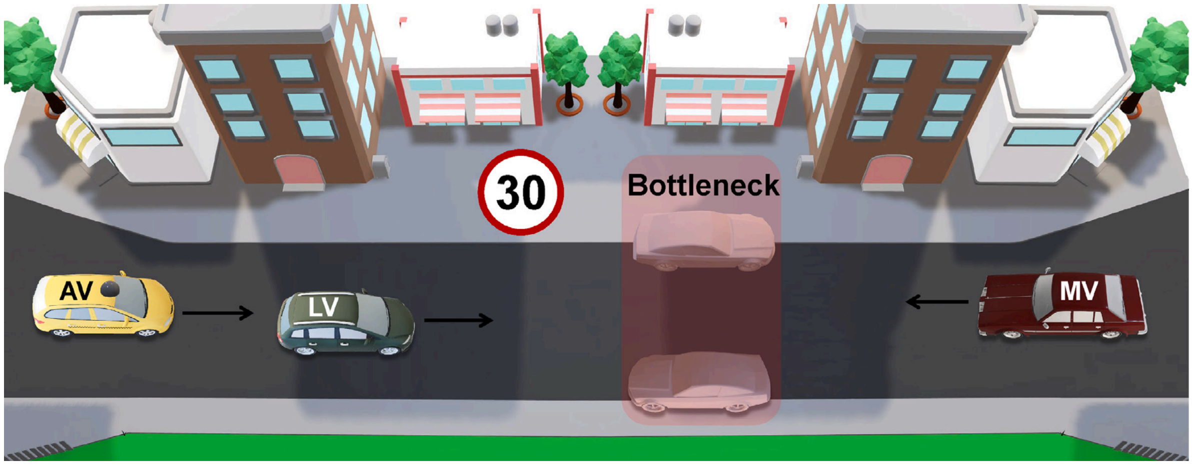


Fig. 1. An example of multi-vehicles on a bottleneck road. The LV blocks the visibility of the MV-driver to the AV. (Speed limit: 30 km/h; AV: automated vehicle; LV: leading vehicle; MV: manually-driving vehicle).

This paper focuses on a bottleneck road, especially with a narrow passing gap and obstacles on both sides (Imbsweiler et al., 2018; Rettenmaier et al., 2019). This type of bottleneck road is one of the ambiguous driving situations where a driver needs to communicate the right-of-way with an oncoming vehicle and decides whether to yield or proceed (Advance Driving School, 2016; Bundesministerium für Justiz und Verbraucherschutz, 2013). As shown in Fig. 1, an MV encounters a leading vehicle (LV) in front of the AV. In this case, the visibility of the MV-driver towards the AV is partially blocked by the LV. The passage is narrowed by two parked vehicles (in grey) on both sides, and only one vehicle can pass at once. We aim to explore an effective communication method in this situation in order to facilitate harmonious traffic sociability and reduce traffic jams and conflicts. To achieve this goal, we explore several different communication strategies to identify an optimal way for AV-MV communication on the bottleneck road.

2. Related work

Generally, two methods are utilised for communication between AVs and other human road users: vehicle kinematics, i. e., implicit communication (Colley et al., 2017; Habibovic et al., 2018) and human–machine interface (HMI), i. e., explicit communication (Rettenmaier et al., 2019; Avsar et al., 2021; Papakostopoulos et al., 2021). On bottleneck roads, in terms of vehicle kinematics, AVs are expected to perform both lateral offset and longitudinal speed adjustment to communicate their right-of-way (Rettenmaier and Bengler, 2021; Miller et al., 2022). For example, Rettenmaier and Bengler (2021), and Miller et al. (2022) report that one-step and two-step deceleration are likely to indicate a vehicle's yielding behaviour, while maintaining speed and acceleration tend to show a vehicle's non-yielding behaviour. In addition, HMIs are further specified as external HMIs (eHMIs) (Dey, 2020; Faas and Baumann, 2019) and internal HMIs (iHMIs) (Li et al., 2022) to facilitate AV-MV communication. eHMIs are deployed outside of an AV to show its messages, and iHMIs are deployed inside an MV to show the messages transferred from the AV.

For eHMIs, many early works mainly focus on the communication between AVs and vulnerable road users (Merat et al., 2018) other than MV-drivers. Specifically, different kinds of eHMIs, such as light patterns (Faas and Baumann, 2019; Lee et al., 2022), and textual (Nissan Motor Corporation, 2015; Liu et al., 2021), symbolic (Rettenmaier and Bengler, 2020) and anthropomorphic (Jaguar and Rover, 2018) signals, were proposed to show an AV's intention and status in order to strengthen the communication between the AV and vulnerable road users, like pedestrians and cyclists, in crossing scenarios. An another type of eHMI is projecting information about right-of-way on the road based on the principle of knowledge-in-the-world, in a way that vulnerable road users are already familiar with (Dey et al., 2021). Moreover, (Li et al., 2021) designs an eHMI to project colours on the road under and in front of the AV, allowing other vulnerable road users in all directions to easily understand the status of the AV from a distance.

For AV and MV-driver communication, eHMIs are explored to increase traffic efficiency and a feeling of safety. Rettenmaier and Bengler (2021) provided an eHMI with orange and green arrows deployed on an AV's bumper that can show its intention to an MV on bottleneck roads. Their method shows an increase in traffic efficiency. Similarly, light-bands on an AV are reported to improve safety feelings and acceptability of AVs at T-junctions (Avsar et al., 2021), strengthen human drivers' confidence, and reduce overall crossing time at intersections (Papakostopoulos et al., 2021). Nonetheless, realistic traffic scenarios are more complicated as the presence of other road users (see Fig. 1), and weather conditions such as foggy, snowy, and rainy days, may heavily impair the visibility of the MV-driver. In this case, the human driver can fail to detect the message on the eHMI when the AV is blocked. Moreover, it was reported that eHMIs only have the potential to optimise AV-MV interaction in bottleneck situations when the AV is visible (Rettenmaier et al., 2019). Liu et al. (2022) also points out that when participants do not easily understand the implicit communication of AVs, their sense of danger will increase, and trust in the AVs will decrease.

To overcome the shortcomings of impaired visibility and ambiguity, the communication between AVs and MVs could be established alternatively by iHMIs with the development of the so-called vehicle-to-vehicle communication system (V2V) (Färber, 2016). It has been predicted that 40% of the vehicles will be equipped with V2V systems by 2030 (Barua et al., 2014). Given that MV-drivers are used to receiving information from iHMIs presented on, e.g., dashboards, head-up displays (HUDs), and central panels, iHMIs can be easily deployed via V2V using those interfaces for conveying AVs' intentions directly to MVs, to mitigate the ambiguous communication between AVs and MVs. For example, Li et al. (2022) propose an iHMI-based communication strategy for AV-MV communication. In their study, AVs' communication information is transferred to MVs based on V2V and displayed on iHMIs using HUDs. The simulation result shows that subjective evaluations of the iHMI have a more favourable score than the eHMI in a scenario where one AV encounters one MV at a bottleneck road. However, it is still not clear whether the benefits of the information on iHMIs or eHMIs outweigh the drawbacks of the added complexity, or whether this balance is maintained across different use cases, especially in more complex scenarios with multiple vehicles (Rettenmaier and Bengler, 2021).

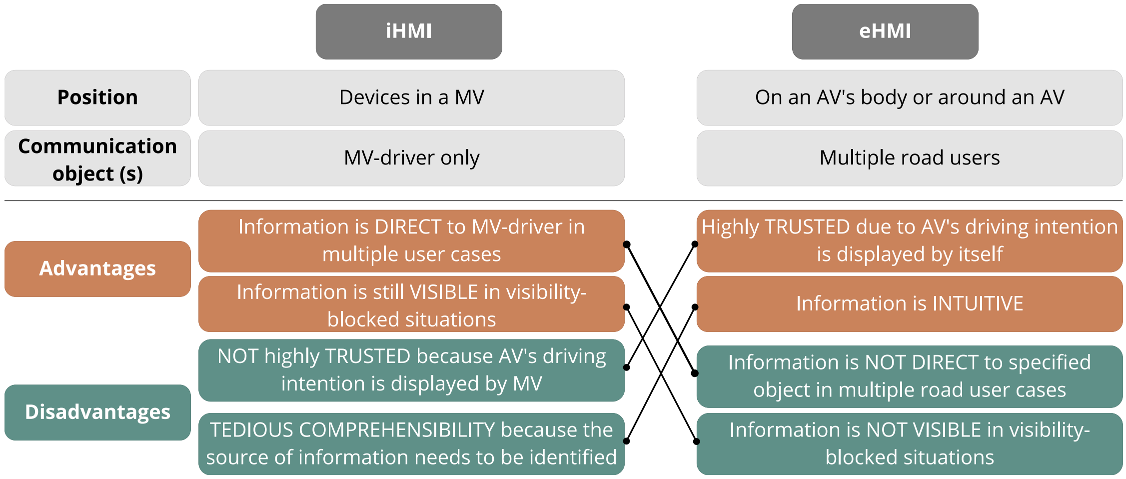


Fig. 2. Advantages and disadvantages of an iHMI and an eHMI as well as their complementary from the MV-driver's viewpoint.

3. Advantages and disadvantages of iHMIs and eHMIs

From an MV-driver's viewpoint, as shown in Fig. 2, we further summarise the advantages and disadvantages of iHMI and eHMI. First, the information is directional from V2V-based iHMIs, i. e., the information sent by the AV can be transmitted to a specified MV-driver. In contrast, eHMI information is broadcast to all the other road users in the vicinity (Merat et al., 2018). Hence, in multi-object scenarios, with an iHMI rather than eHMI, an MV-driver can clearly understand whether the communicating object is him/her or not.

Second, the information of iHMIs in the vehicle is not impaired by the occlusion of other vehicles, even in traffic congestion and low visibility weather conditions such as foggy, snowy, and rainy days. On the other hand, the eHMI deployed on an AV body or projected on the road is invisible or partly invisible in situations when an MV-driver's vision is obstructed. For example, Rettenmaier et al. (2019) report that eHMIs can only optimise the AV-MV interaction during a bottleneck situation when the AV is visible to the MV-driver.

A typical disadvantage of V2V-based iHMI is that the information from an AV is relayed by the MV's iHMI, which the AV does not directly show. In comparison, an AV can display its intention directly with its eHMI. Hence, compared to the relayed information displayed on the MV's iHMI, the MV-driver may have higher trust when the information is directly represented on the AV's eHMI.

Another disadvantage of iHMI is that an MV-driver may not immediately recognise who is sending the information. In other words, after receiving the information through iHMIs, the MV-driver must find the information sender in various environments and match the sender's intention. In contrast, the information on eHMI deployed on an AV's body or projected on the road accurately indicates where the information comes from. Thus, eHMIs can be more intuitive and precise than iHMIs in multiple road user situations.

4. Proposition and Hypotheses

4.1. Proposition

This paper proposes a synchronous HMI for AV and MV-driver communication based on the analysis of the advantages and disadvantages of iHMIs and eHMIs. It allows an iHMI in an MV and an eHMI on an AV to display the same information about the AV's intention simultaneously. The synchronous HMI proposes a novel way to make up for single displayed HMIs — it aggregates the directability and visibility of iHMI and a higher sense of relief and intuition of eHMIs. We call this synchronous HMI *iHMI+eHMI* in this paper.

4.2. Hypotheses

In order to find potential and proper communication strategies in real traffic scenarios with multiple road users, the following four hypotheses are explored. The effectiveness of the proposed *iHMI+eHMI* is compared with three variant settings, *iHMI* only, *eHMI* only, and implicit communication by an AV's kinematics only, i. e., no HMI on the AV (*w/o HMI*) as a baseline design in this study.

H1. Compared with the explicit communication methods (*eHMI*, *iHMI* and *iHMI+eHMI*), the implicit communication method (i. e., *w/o HMI*) is insufficient for comprehensibility, feeling of safety, efficiency of AV-MV communication, and building trust and acceptance of AVs.

H2. Compared with single-display *iHMI* or *eHMI*, *iHMI+eHMI* can improve drivers' comprehensibility, feeling of safety, and efficiency of AV-MV communication. Furthermore, it can build trust and acceptance of AVs.

5. Method

In this paper, to fix the driving behaviours of the MV, LV, and AV in different trials using multiple HMIs, a video-based experiment was administered. In this experiment, an online study including videos and post-trial questionnaires was used to analyse participants' subjective feelings about the four types of HMIs focused on a bottleneck road with multiple vehicles. This work differs from our previous study (Li et al., 2022) that also focuses on AV-MV communication with *iHMI*, *eHMI*, and *iHMI+eHMI* in bottleneck roads in the following ways: (1) We consider a more complex traffic environment with not only the interaction between two vehicles but with interactions among multiple vehicles; (2) The MV-driver's view is partially obscured by another vehicle in front of the AV, which is practically common in a realistic traffic environment, such as traffic jams.

This research was carried out in accordance with the *Declaration of Helsinki ethical principles*. All the participants provided their *informed consent* before participating in the studies.

5.1. The HMI designs for AV-MV communication

Fig. 3 demonstrates the *iHMI* and *eHMI* designs for AV-MV communication on a bottleneck road. We adopt a popular eHMI design proposed by a previous study (Li et al., 2021) – the communication is achieved by projecting the AV's intention onto the road (in front of and beneath the AV). In this study, a red ova light (R = 184, G = 29, B = 19) indicates that the AV is decelerating and will stop, showing its intention

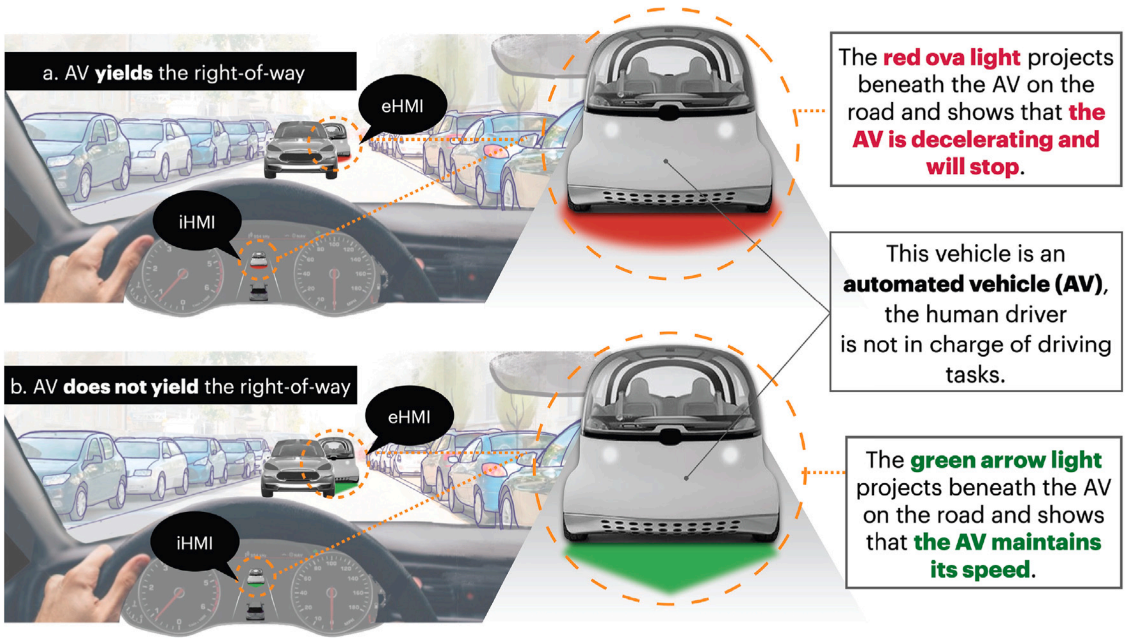


Fig. 3. The demonstration of the proposed *iHMI* and *eHMI*. The *iHMI* displays its information on the MV's dashboard. In contrast, the *eHMI* is located beneath and in front of the AV and projects its intention on the road using different colours. *iHMI+eHMI* enables *iHMI* and *eHMI* to display the same information synchronously. a. shows that the AV yields its right-of-way to the MV, while b. shows that the AV does not yield. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

to yield to the MV, and a green arrow light (R = 76, G = 187, B = 23) indicates that the AV maintains its speed, showing its intention to insist on its right-of-way. The *iHMI* is designed identically to the *eHMI* but it is located on the MV's dashboard. In total, three types of HMI designs are leveraged in this study: *eHMI*, *iHMI*, and *iHMI+eHMI*. We treat the case of no HMI on the AV (*w/o HMI*) as the baseline design. For the sake of simplicity, if not otherwise stated, our four types of communication strategies are written in italics in this paper.

It should be noted that, in this paper, we do not focus on the detailed HMI designs, but rather on the performance of the combined *iHMI+eHMI*, i. e., whether it provides adequate information or is considered redundant in the bottleneck road situation. We leave the high-fidelity design to future work.

5.2. Online simulator study

We prepared a video-based online simulator study with structured questionnaires to analyse: (1) compared to the baseline design, if HMIs are needed on a bottleneck road with multiple road users; (2) compared to the single *iHMI* or *eHMI*, if the *iHMI+eHMI* has a more positive subjective evaluation.

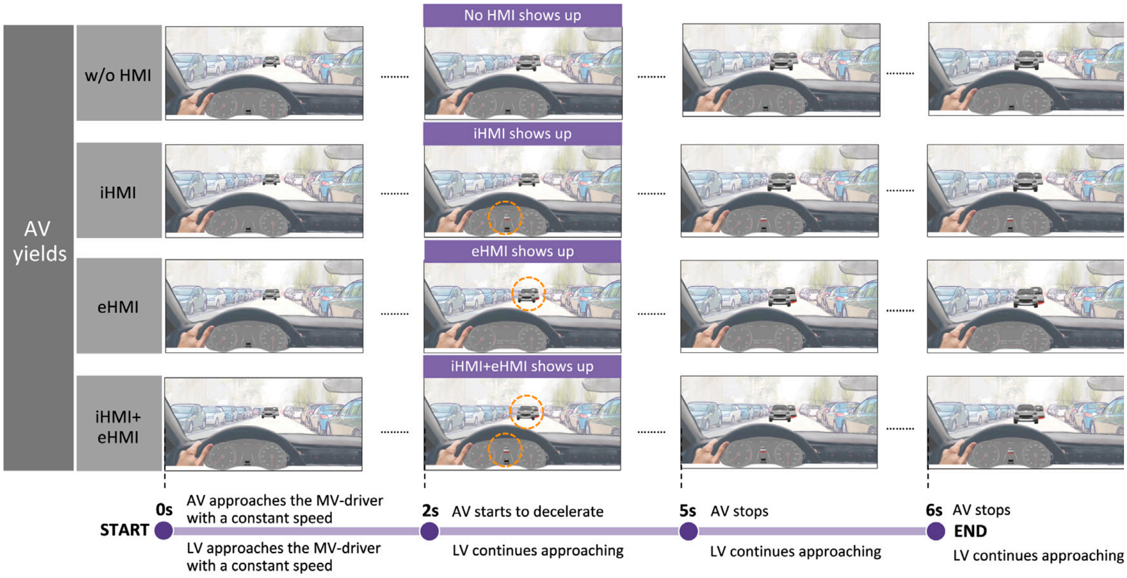
As shown in Fig. 4, the videos simulate multiple vehicle interaction scenarios on a bottleneck road. Two types of behaviour displayed by the AV (yields and does not yield the right-of-way) with four interfaces (*w/o HMI*, *iHMI*, *eHMI*, and *iHMI+eHMI*) are demonstrated. Specifically, an LV in front of the AV always drives with non-yielding behaviour, i. e., passing through the bottleneck road at a constant speed (20 km/h). Following the LV, if the AV yields the right-of-way, it decelerates from 20 km/h to 0 km/h (stopping) to indicate its yielding behaviour, as shown in Fig. 4(a). Concurrently with deceleration, the HMIs are turned on to show the yielding information (see Section 5.1). If the AV insists on its right-of-way, the AV follows the LV and approaches at a steady speed of about 20 km/h (maintaining) to indicate the non-yielding behaviour, as shown in Fig. 4(b). At the same time as determining non-yielding intention, the HMIs are turned on to show the corresponding information (see Section 5.1). In the baseline (*w/o HMI*) setting, only AV movements are available, and there is no HMI shown.

The online simulator study took approximately 20 min after the personal data policy statement. It was structured in four sections as follows:

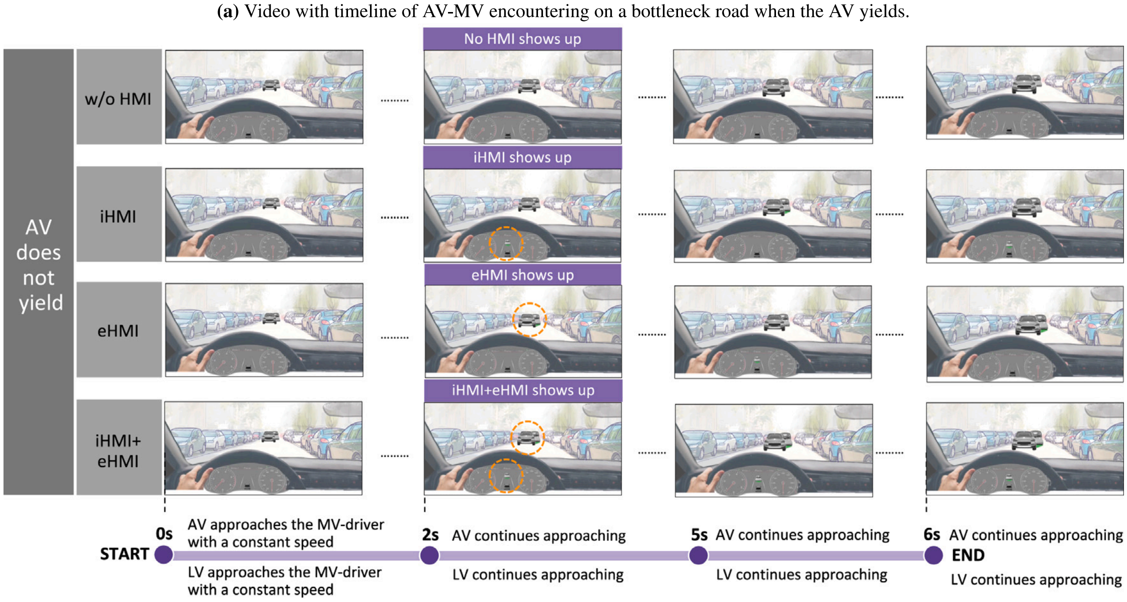
(1) **Demographic Survey:** We asked the attendees to fill in a demographic questionnaire, including questions about their age, gender, and prior driving experience on bottleneck roads.
(2) **Bottleneck road introductory video:** A three-minute realistic driving video was shown to the participants. The videos were recorded on bottleneck roads in the urban area of the city of Karlsruhe, Germany. This video assists them in recalling and immersing themselves in the situations based on their driving experience. After that, we asked how often the participants drove on bottleneck roads.
(3) **HMI instruction:** We described designs of these three HMIs specifically in order to make sure that the participants understood the information conveyed to them, as shown in Fig. 3.
(4) **Eight experimental videos with post-trial questionnaires:** The participants were asked to watch eight videos including two types of driving behaviour of the AV (i. e., yielding and non-yielding) with the four types of HMIs, as shown in Fig. 4. In order to control carry-over effects, the order of the videos followed by the post-trial questionnaires handed out to the participants was randomised. After each video, the participants needed to evaluate the HMIs in terms of *comprehensibility*, *feeling of safety*, *trust*, *efficiency, and acceptance* with using different communication strategies. At the end of the study, the participants were asked to give an overall assessment of the *iHMI*, *eHMI* and *iHMI+eHMI*, as well as the baseline design.

5.3. Participants

A total of $N = 24$ participants (8 females and 16 males) between the age of 28 and 40 years ($M = 31.25$, $SD = 7.54$) took part in this study. All of them had a German driver's license. Most participants had good experiences driving on bottleneck roads, i.e., 4 participants drove almost every day, 11 participants drove at least once a week, and 5 participants drove at least once a month. The participants were



(a) Video with timeline of AV-MV encountering on a bottleneck road when the AV yields.



(b) Video with timeline of AV-MV encountering on a bottleneck road when the AV does not yield.

Fig. 4. Videos of AV-MV encountering on a bottleneck road (This video recording is from the MV-driver (participant)'s view). (a) The approaching AV yields to the MV. At the start of the video, both the AV and the LV approach the MV with a constant speed. After two seconds, the AV starts to decelerate and the HMIs show up (except for *w/o HMI*) while the LV continues approaching. At the fifth second, the AV stops but the LV continues approaching until the end of the video. (b) The approaching AV does not yield to the MV. Both the AV and the LV approaches the MV at a constant speed continuously until the end of the video. At the second, the HMIs show up (except for *w/o HMI*). Note that the duration of all the videos is the same, which is six seconds. The orange circles are used to highlight the HMIs in this figure, but they were not shown to participants in the online simulator study.

compensated with a € 5 of Amazon voucher for their participation if they had finished all the required questions.

5.4. Measurements

After each video of the different HMIs and the baseline group *w/o HMI*, the participants were asked to evaluate the communication between the AV and MV according to the following perspectives:

- **Comprehensibility**: We concluded two sub-items, i.e., **item 1** "the communication is clear" and **item 2** "the communication is adequate" (Matthews et al., 2017);
- **Feeling of safety**: **item 3** "I feel safe when I communicate with AV in this situation" (Liu et al., 2021);
- **Trust in AV**: **item 4**: We concluded two sub-items, i.e., "I trust the AV will take appropriate actions" and **item 5** "I trust the AV more than the leading vehicle when it communicates with me in this way in this situation" (Liu et al., 2021; Matthews et al., 2017);
- **Efficiency**: **item 6** "This communication strategy of the AV is efficient for me to decide to go or wait" (Mandrick et al., 2016);
- **Acceptance**: We adopted the following bipolar items from the acceptance questionnaire by Van Der Laan et al. (1997). The sub-scale of satisfaction was used to reflect participants' attitudes towards the AV in this study, i. e., **item 7** "unpleasant or pleasant", **item 8** "annoying or nice", **item 9** "irritating or likeable", and **item 10** "undesirable or desirable".

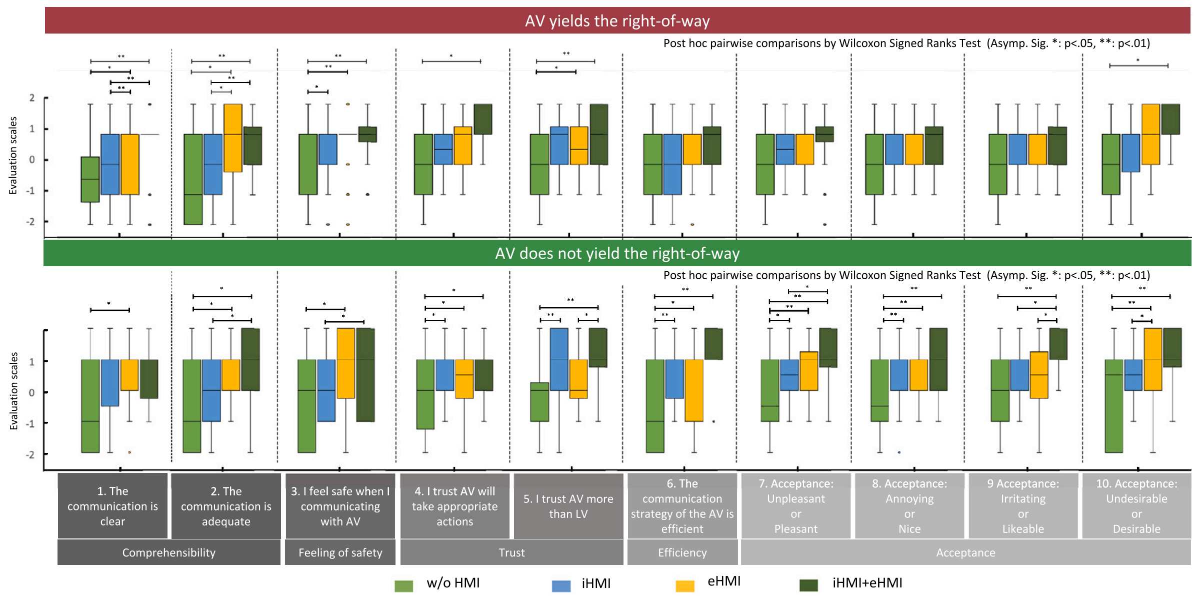


Fig. 5. Subjective evaluation results of the AV-MV's communication from participants (MV-drivers), horizontal lines in the boxes represent the median of the ratings.

Table 1
Cronbach's Alpha of the sub-items of comprehensibility, trust, and acceptance.

Subjective feeling items	Number of items	Cronbach's Alpha
Comprehensibility	2	.804
Trust	2	.846
Acceptance	4	.933

The items 1–6 were rated on a 5-point Likert scale, namely, −2 "strongly disagree", −1 "disagree", 0 "neutral", 1 "agree", and 2 "strongly agree". Items 7 to 10 were evaluated in a 5-point bipolar scale from −2 to + 2, corresponding to bilateral attitudes. In these cases, zero reference point means that participants have a neural attitude on both sides.

At the end of the study, we did an overall assessment with the following question: "which communication strategy do you like most to communicate with the AV when it yields/does not yield the right-of-way in this situation? (choose only one option)". The selection rate of each HMI was later analysed.

6. Results

We evaluate the effect of communication strategies on subjective feelings about comprehensibility, feeling of safety, trust, efficiency, and acceptance. Since the 5-point Likert scale was used to measure subjective feelings for each evaluation item, non-parametric related-samples Friedman's ANOVA (two-sided) followed by Wilcoxon signed ranks test for the post-hoc pairwise comparisons were applied. The corresponding results of "AV yields the right-of-way to MV" and "AV does not yield the right-of-way to MV" are presented in Fig. 5. The vertical axis shows the scores of the 5-point Likert scale, and the horizontal axis indicates items of subjective feelings. The horizontal line in each bar represents the median of the rating. The results of all the evaluation items, regardless whether the AV behaves yielding or not yielding the right-of-way, *w/o HMI* scores the lowest median, while *iHMI+eHMI* scores the highest median. Cronbach's alpha was used to measure the internal reliability of the questions that have sub-items. As shown in Table 1, Cronbach's Alpha of Comprehensibility, trust and acceptance overcome the threshold of 0.7, which proves the internal consistency reliability across the sub-items (Gerbing and Anderson, 1988).

6.1. When approaching AV yields the right-of-way

From the results of Friedman's ANOVA, when the AV yields (see Table 2), statistically significant differences are found regarding item 1: communication is clear ($p < .05$), item 2: communication is adequate ($p < .01$), item 3: feeling of safety ($p < .01$), item 5: trust AV more than LV ($p < .05$). There is no significant difference regarding item 4: trust AV will take appreciate actions, item 6: the communication strategy is efficient, and items 7–10: acceptance of AV. When the AV does not yield (see Table 2), no significance is found in item 1, but statistically significant differences are found in items 2, 5, 6, 7, 8, 10 ($p < .01$), and items 3, 4, 9 ($p < .05$).

From the results of the post-hoc pairwise comparisons by the Wilcoxon signed ranks test, when AV yields the right-of-way (see Table 3), the communication via *iHMI+eHMI* and *eHMI* regarding comprehensibility scores the same highest median (1.0), while the median of *iHMI* is 0.0. The communication with *eHMI* is significantly clearer and more adequate than *w/o HMI* and *iHMI* ($p < .05$). Moreover, the communication with *iHMI+eHMI* is also significantly clearer and more adequate than*w/o HMI* and *iHMI* ($p < .01$). Compared to communication by *w/o HMI*, MV-driver's "feeling of safety" is significantly higher via *iHMI*, *eHMI* and *iHMI+eHMI* ($p < .05$, $p < .01$, $p < .01$, respectively). However, there is no significant difference across the types of HMI regarding the feeling of safety. Regarding trust-related evaluation items, when the participants communicate via *iHMI+eHMI*, they significantly "trusted AV will take appropriate actions" compared to communicating via *w/o HMI* ($p < .05$). Both *iHMI+eHMI* and *eHMI* led to a significantly higher score for "trusted AV more than LV" compared to *w/o HMI* ($p < .01$, $p < .05$, respectively). Moreover, the communication with *iHMI+eHMI* leads to a significantly higher score for "trusted AV more than LV" compared to *iHMI* ($p < .05$). There are no significant differences across the four types of HMI in the rest of the evaluation items i. e., efficiency and acceptance. Except for item 10, the evaluation of the communication with *iHMI+eHMI* is significantly higher compared to *w/o HMI* ($p < .05$).

6.2. When approaching AV does not yield the right-of-way

When AV does not yield the right-of-way (see Table 4), the communication with *eHMI* significantly improves the clearness of the communication compared to *w/o HMI* ($p < .05$). But no significant differences are found among the types of HMI regarding item 1 "the communication is clear".

Table 2
Related-Samples Friedman's ANOVA by Ranks (two-sided) for each evaluation item ($n = 24$).

		Comprehensibility		Feeling of safety	Trust		Efficiency	Acceptance			
		The communication is clear	The communication is adequate	I feel safe when I communicate with AV	I trust AV will take appropriate actions	I trust AV more than LV	The AV communication strategy is efficient	Unpleasant or Pleasant	Annoying or Nice	Irritating or Likeable	Undesirable or Desirable
AV yields	*F*	9.441	13.047	12.865	3.479	10.665	5.946	4.741	3.249	2.328	5.579
	p	**.024**	**.005**	**.005**	.323	**.014**	.114	.192	.355	.507	.134
AV does not yield	*F*	4.624	11.592	9.179	10.288	15.685	16.365	16.516	12.087	11.022	11.983
	p	.201	**.008**	**.027**	**.016**	**.001**	**.001**	**.001**	**.007**	**.012**	**.007**

Table 3
Post hoc pairwise comparisons by Wilcoxon signed ranks test for each evaluation item when AV yields the right-of-way ($n = 24$).

		Comprehensibility		Feeling of safety	Trust		Efficiency	Acceptance			
		Item 1 The communication is clear	Item 2 The communication is adequate	Item 3 I feel safe when I communicate with AV	Item 4 I trust AV will take appropriate actions	Item 5 I trust AV more than LV	Item 6 The AV communication strategy is efficient	Item 7 Unpleasant or Pleasant	Item 8 Annoying or Nice	Item 9 Irritating or Likeable	Item 10 Undesirable or Desirable
w/o HMI vs. *iHMI*	*Z*	−1.022	−.915	−2.246	−.680	−1.776	−.736	−1.114	−1.054	−.618	−.691
	p	.307	.360	**.025**	.496	.077	.462	.265	.292	.537	.490
w/o HMI vs. *eHMI*	*Z*	−2.137	−2.372	−3.189	−1.298	−.2346	−1.528	−1.291	−.947	−.821	−1.425
	p	**.033**	**.018**	**.001**	.194	**.019**	.126	.197	.344	.412	.154
w/o HMI vs. *iHMI+eHMI*	*Z*	−2.832	−2.811	−3.229	−2.335	−2.914	−1.938	−1.802	−1.842	−1.822	−2.538
	p	**.005**	**.005**	**.001**	**.020**	**.004**	.053	.071	.065	.068	**.011**
iHMI vs. *eHMI*	*Z*	−2.099	−2.087	−1.434	−.806	−.522	−1.224	−.611	−.227	−.382	−.877
	p	**.036**	**.037**	.151	.420	.602	.221	.541	.821	.702	.381
iHMI vs. *iHMI+eHMI*	*Z*	−2.876	−3.161	−1.745	−1.842	−1.227	−1.742	−1.163	−.966	−1.119	−1.930
	p	**.004**	**.002**	.081	.065	**.021**	.082	.245	.334	.263	.054
eHMI vs. *iHMI+eHMI*	*Z*	−1.252	−4.454	−.405	−1.035	−.924	−.613	−.644	−1.032	−1.164	−1.417
	p	.210	.650	.685	.301	.356	.540	.519	.302	.244	.156

Table 4
Post hoc pairwise comparisons by Wilcoxon signed ranks test for each evaluation item when AV does not yield the right-of-way ($n = 24$).

		Comprehensibility		Feeling of safety	Trust		Efficiency	Acceptance			
		Item 1 The communication is clear	Item 2 The communication is adequate	Item 3 I feel safe when I communicate with AV	Item 4 I trust AV will take appropriate actions	Item 5 I trust AV more than LV	Item 6 The AV communication strategy is efficient	Item 7 Unpleasant or Pleasant	Item 8 Annoying or Nice	Item 9 Irritating or Likeable	Item 10 Undesirable or Desirable
w/o HMI vs. *iHMI*	*Z*	−1.807	−1.220	−.446	−2.022	−2.645	−2.668	−2.430	−2.600	−1.786	−1.715
	p	.071	.223	.655	**.043**	**.008**	**.008**	**.015**	**.009**	.074	.086
w/o HMI vs. *eHMI*	*Z*	−2.494	−2.410	−2.464	−1.992	−1.826	−2.219	−2.697	−2.648	−1.646	−2.608
	p	**.013**	**.016**	**.014**	**.046**	.068	**.026**	**.007**	**.008**	.100	**.009**
w/o HMI vs. *iHMI+eHMI*	*Z*	−1.958	−2.234	−1.579	−2.583	−3.416	−3.205	−3.174	−3.194	−2.782	−2.661
	p	.050	**.026**	.114	**.010**	**.001**	**.001**	**.002**	**.001**	**.005**	**.008**
iHMI vs. *eHMI*	*Z*	−1.101	−1.412	−1.848	−.353	−1.211	−.032	−.843	−.370	−.122	−.699
	p	.271	.158	.065	.724	.226	.974	.399	.711	.903	.485
iHMI vs. *iHMI+eHMI*	*Z*	−.919	−2.360	−2.150	−.426	−1.463	−1.458	−2.553	−1.035	−2.351	−2.164
	p	.358	**.018**	**.032**	.670	.143	.145	**.011**	.301	**.019**	**.030**
eHMI vs. *iHMI+eHMI*	*Z*	−.640	−9.79	−2.84	−1.303	−2.438	−1.605	−1.590	−1.368	−1.989	−1.144
	p	.522	.328	.777	.193	**.015**	.108	.112	.171	**.047**	.252

Communication with both *iHMI+eHMI* and *eHMI* are significantly more adequate than *w/o HMI* ($p < .05$), and communication with *iHMI+eHMI* is significantly more adequate than *iHMI* ($p < .05$). *eHMI* significantly improve participants' "feeling of safety" when communicating with AV compared to *w/o HMI* ($p < .05$), while *iHMI+eHMI* shows significantly higher score than *iHMI* ($p < .05$). Regarding the evaluation items of trust, the participants have a significantly higher trust in that the "AV will take appropriate actions" by the communication via *iHMI*, *eHMI* and *iHMI+eHMI* compared to the communication via *w/o HMI* ($p < .05$). Both *iHMI+eHMI* and *iHMI* lead to participants "trust the AV more than LV" compared to *w/o HMI* respectively ($p < .01$), among the types of HMIs, *iHMI+eHMI* shows significantly higher score than *eHMI* ($p < .05$). Compared to *w/o HMI*, the communication with *iHMI*, *eHMI*, and *iHMI+eHMI* significantly improves participants' perceived efficiency when they communicated with the AV ($p < .01$, $p < .05$, $p < .01$, respectively). The communication with *iHMI*, *eHMI* and *iHMI+eHMI* significantly improves participants' acceptance of AV. No significant differences across *iHMI*, *eHMI*, and *iHMI+eHMI* are found in other acceptance evaluation items. Except for item 9, the evaluation of the communication with *iHMI+eHMI* is significantly higher than *w/o HMI* ($p < .01$), *iHMI* ($p < .05$) and *eHMI* ($p < .05$).

6.3. Overall assessment

Fig. 6 shows the results of the overall assessment across the three communication strategies. When the AV yields the right-of-way, 8.3%, 33.4% and 58.3% of the participants prefer to communicate with *iHMI*, *eHMI* and *iHMI+eHMI*, respectively. Also, when the AV insists on its

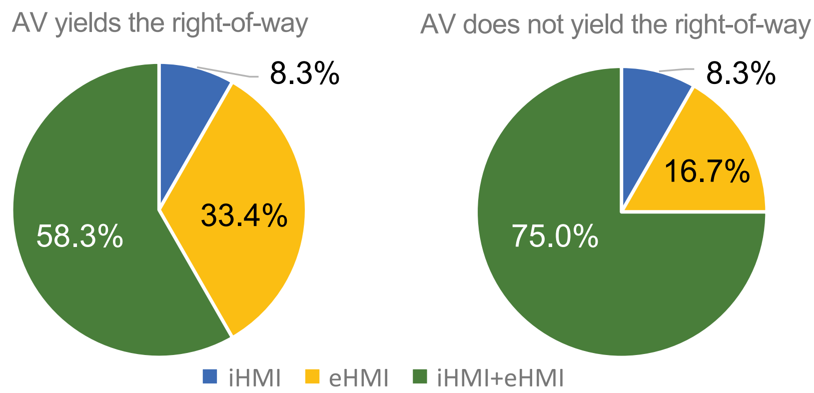


Fig. 6. The overall assessment of *iHMI*, *eHMI* and *iHMI+eHMI* ($N = 24$).

right-of-way, 8.3%, 16.7% and 75.0% of the participants prefer to communicate with *iHMI*, *eHMI* and *iHMI+eHMI*, respectively.

In summary, according to reports from the participants, *iHMI+eHMI* has the highest assessment amongst the other types of HMIs when AV behaves yielding and not yielding the right-of-way.

7. Discussion

In this study, we measured how the participants' subjective feelings in terms of comprehensibility, feeling of safety, efficiency, trust, and acceptance of AV were influenced by the types of communication strategies on bottleneck roads with blocked visibility. Through a video-based online simulator study, we explored whether the benefits of the extra communication information on HMI could compensate for the lack of communication between AV and MV or if it adds more complexity. Moreover, we further validate our hypotheses based on the experimental results in the following sections.

7.1. Hypotheses

Hypothesis 1. *Compared with the explicit communication methods (eHMI, iHMI and iHMI+eHMI), the implicit communication method (i. e., w/o HMI) is insufficient for comprehensibility, feeling of safety, efficiency of AV-MV communication, and building trust and acceptance of AVs.* H1 can be accepted as the results illustrated that in the visibility-blocked traffic scenarios, the explicit communication information, whether *iHMI*, *eHMI* or *iHMI+eHMI*, can help the MV-driver understand the intention of the AV. Thus, the MV-driver feels safer, and the communication is more efficient, which in turn helps the MV-driver improve their trust in and acceptance of the AV regardless whether the AV yields or insists on its right-of-way. These results are in line with the studies of Imbsweiler et al. (2018), Rettenmaier and Bengler (2021), and Liu et al. (2021) on the evaluation of eHMIs for communications between AVs.

Hypothesis 2. *Compared with single-display iHMI or eHMI, iHMI+eHMI can improve drivers' comprehensibility, feeling of safety, and efficiency of AV-MV communication. Furthermore, it can build trust and acceptance of AVs.* H2 is partly accepted according to the experimental results. When the AV yields right-of-way, subjective evaluation results show that *iHMI+eHMI* has significantly higher comprehensibility scores than *iHMI* and *eHMI*. Although there are no significant differences in the remaining ten evaluation items, we can still see that *iHMI+eHMI* has a higher median than that of *iHMI* and *eHMI*, respectively. When AV does not yield the right-of-way, participants' comprehensibility and the feeling of safety are significantly higher using *iHMI+eHMI* than using *iHMI* or *eHMI*. In addition, participants trust the AV more than the LV when they communicate using *iHMI+eHMI* compared to *eHMI* and *iHMI*.

7.2. Further discussion

Interestingly, when AV yields, although the median of *iHMI*, *eHMI* and *iHMI+eHMI* are higher than *w/o HMI*, no significant differences were found between the communication strategies. However, when AV does not yield, participants report a significantly higher AV acceptance communicating with *iHMI*, *eHMI* and *iHMI+eHMI* compared to *w/o HMI*. This finding suggests that when AV does not yield, the extra communication information on HMI could improve MV-driver's acceptance of AV. In terms of *iHMI*, the MV-driver first needs to match the information shown on *iHMI* into the traffic situations. It is more difficult in the multiple-vehicle scenario. Subsequently, the MV-driver needs to interpret the AV's intention based on the traffic context, This process increases the difficulty of comprehending the communication between AV and MV-driver. Thus, this result suggests that *eHMI* or *iHMI+eHMI* are more comprehensive compared to *iHMI*. In addition, participants report a significantly more adequate communication using *iHMI+eHMI* compared to *w/o HMI* and *iHMI*, respectively. However, no significant differences were found in the evaluation of the item "communication is clear" between *w/o HMI* and *iHMI+eHMI*, *iHMI* and *iHMI+eHMI* when AV does not yield. This result suggests that even the implicit information from the AV or the single displayed *iHMI* could provide sufficient clarity of the communication, participants may still expect more intuitive information from AVs. Interestingly, there are no significant differences regarding trust between *iHMI* and *eHMI* when the AV is conducting yielding or non-yielding behaviour. However, the median of *iHMI* is higher than that of *eHMI*, indicating that the participants trust more in the AV when communicating via *iHMI*. The reason could be that although we explained the meaning of the types of HMIs to the participants at the beginning of the experiment, this *eHMI* is still a new design for the participants as a novel communication message in a traffic environment. As discussed by Rettenmaier et al. (2019), eHMIs are only optimal when the users are familiar with them. The participants may need more time to become familiar with the eHMIs and build trust.

To summarise, the combination of *iHMI* and *eHMI*, i. e., *iHMI+eHMI* helps the MV-driver feels safer, and the communication is more efficient, which in turn helps the MV-driver improve their trust and acceptance of the AV regardless of whether the AV yields or insists on its right-of-way using for communication of AVs and MV-drivers. Furthermore, the overall assessment shown in Fig. 6 indicates that most participants have chosen the synchronous HMI for AV-MV communication. Hence, the synchronous HMI provides a double-check option to the participants. In this way, the redundant information displayed on both *iHMI* and *eHMI* can significantly improve the MV-driver's comprehensibility of the AV's intention. In other words, *eHMI* helps the participants understand from whom the information is sent intuitively, and *iHMI* helps them easily identify to whom the information is sent. Therefore, the source and target of the information displayed on the *iHMI+eHMI* is clearer, which helps participants trust the information sent from the AV and in turn, improves their acceptance of the AV. This result is consistent with Liu et al. (2021) for trust between an AV and pedestrians—a clear understanding of the information transmitted from the AV can improve pedestrians' trust in it.

7.3. Contributions

Previous studies have focused on how eHMI affects AV-MV communication on bottleneck roads with one target, i. e., there are only one AV and one MV in the test scenarios. Our work focused on a scenario with the MV-driver being visually blocked, which is very common in traffic jam situations. A new HMI-based communication strategy: a synchronous HMI (*iHMI+eHMI*), was proposed to aggregate the advantages of *iHMI* and *eHMI*. The results showed that whether AV yields or takes the right-of-way, the synchronous HMI gains the highest score in comprehensibility, feeling of safety, efficiency, and trust in and acceptance of AV, compared to *w/o HMI*, *iHMI* and *eHMI*, respectively.

7.4. Limitations and future works

In order to fix the kinematics of the MV and its distances to the LV and AV during the trials, the participants were not allowed to drive the MV based on their own intention. In realistic scenarios, driving intentions from individual drivers of the MV may affect the understanding of the information transferred from the AV.

Another limitation is that most of the participants are young males. They cannot fully represent the subjective feelings of AV-MV communication across all user groups. To reduce the potential effects of age and even gender, a balanced sample should be considered in the next-step experiment. Even though the G-power (Faul et al., 2009) showed that the results from 24 participants have a medium effect size (0.25) (Funder and Ozer, 2019) in this study, a driving simulator experiment with a larger sample size is under our plan to further verify the results of this study. In addition, the videos used in this study are based on videos recorded in Germany. The results of this experiment may only apply to situations in Germany.

8. Conclusion

AV's ambiguous and invisible intention poses communication issues between AV and MV in unclear right-of-way scenarios. In this paper, we focused on bottleneck roads with blocked visibility as a more complex scenario—more than one target compared to previous studies, and MV drivers who cannot easily receive communication information from the oncoming AVs due to the blocked visibility. This scenario is very common in various realistic traffic situations, especially traffic jam situations. To find a potential solution to this issue, we aggregated the advantages of an AV-based eHMI and a V2V-based iHMI, and proposed a synchronised iHMI+eHMI to better support AV-MV communication. An online simulator study was used to evaluate whether *iHMI+eHMI* has better subjective evaluation in terms of comprehensibility, feeling of safety, trust, efficiency, and acceptance of AV-MV communication on a bottleneck road scenario with multiple vehicles. From the results, first of all, we confirmed that HMI is needed in AV-MV communication on the bottleneck road regardless whether the AV yields or does not yield the right-of-way. Secondly, when the AV yields, we also found that *iHMI+eHMI* has higher ratings in all the subjective evaluations compared with the single displayed iHMI or eHMI, except for the ratings for acceptance of the AV. When AV does not yield, communicating with *iHMI+eHMI* makes the MV-driver gain clearer comprehensibility, feel safer and more efficient in AV-MV communication, and have higher trust in and acceptance of the AV compared to the communication with the single displayed HMIs. This new communication strategy iHMI+eHMI could be expanded and measured in multiple road-users' ambiguous scenarios, such as T-junctions and intersections.

Our next step works will further cross-validate driving simulator, naturalistic, and traffic observation studies in a realistic traffic environment. These experiment methodologies will explored to determine how the communication strategy should be applied to various complex and ambiguous AV-MV communication scenarios.

CRediT authorship contribution statement

Yang Li: Conceptualization, Investigation, Methodology, Conducting the experiment, Formal analysis, Writing – original draft. **Hao Cheng:** Conceptualization, Methodology, Writing – review & editing. **Zhe Zeng:** Formal analysis, Writing – review & editing. **Barbara Deml:** Conceptualization, Writing – review & editing. **Hailong Liu:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 20K19846, Japan; and Remote Collaboration Program of Karlsruhe House of Young Scientist (KHYS), Germany. Yang Li is supported by China Scholarship Council (CSC) (No. 201906260302) at Karlsruhe Institute of Technology (KIT), Germany. Hao Cheng is funded by MSCA European Postdoctoral Fellowships under the 101062870 - VeVuSafety project.

References

Advance Driving School, 2016. Automated vehicle for safety. URL: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety#the-topic-benefits. (Accessed: 08 August 2022).

Avsar, H., Utesch, F., Wilbrink, M., Oehl, M., Schießl, C., 2021. Efficient Communication of Automated Vehicles and Manually Driven Vehicles Through an External Human-Machine Interface (eHMI): Evaluation at T-Junctions. In: International Conference on Human-Computer Interaction. Springer, pp. 224–232.

Barua, N., Natarajan, P., Chandrasekar, P., Singh, S., 2014. Strategic Analysis of the European Market for V2V and V2I Communication Systems. Frost & Sullivan Report MA29-18.

Bundesministerium für Justiz und Verbraucherschutz, 2013. Straßenverkehrs-ordnung (STVO) §11 besondere verkehrslagen. URL: https://www.gesetze-im-internet.de/stvo_2013/_11.html. accessed: 2022-04-27.

Colley, A., Häkkilä, B., Alt, F., 2017. A design space for external displays on cars. In: Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct. pp. 146–151.

Dey, D., 2020. External Communication for Self-Driving Cars: Designing for Encounters Between Automated Vehicles and Pedestrians, Industrial Design (Ph.D. thesis). Technische Universiteit Eindhoven, Proefschrift.

Dey, D., van Vastenhoven, A., Cuijpers, R.H., Martens, M., Pfleging, B., 2021. Towards scalable eHMIs: Designing for AV-VRU communication beyond one pedestrian. In: 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. pp. 274–286.

Faas, S.M., Baumann, M., 2019. Yielding light signal evaluation for self-driving vehicle and pedestrian interaction. In: International Conference on Human Systems Engineering and Design: Future Trends and Applications. Springer, pp. 189–194.

Färber, B., 2016. Communication and communication problems between autonomous vehicles and human drivers. In: Autonomous Driving. Springer, pp. 125–144.

Faul, F., Erdfelder, E., Buchner, A., Lang, A.G., 2009. Statistical power analyses using g* power 3.1: Tests for correlation and regression analyses. Behav. Res. Methods 41, 1149–1160.

Fuest, T., Feierle, A., Schmidt, E., Bengler, K., 2020. Effects of marking automated vehicles on human drivers on highways. Information 11, 286.

Fuest, T., Sorokin, L., Bellem, H., Bengler, K., 2017. Taxonomy of traffic situations for the interaction between automated vehicles and human road users. In: International Conference on Applied Human Factors and Ergonomics. Springer., pp. 708–719.

Funder, D.C., Ozer, D.J., 2019. Evaluating effect size in psychological research: Sense and nonsense. Adv. Methods Pract. Psychol. Sci. 2, 156–168.

Gerbing, D.W., Anderson, J.C., 1988. An updated paradigm for scale development incorporating unidimensionality and its assessment. J. Mar. Res. 25, 186–192.

Habibovic, A., Lundgren, V.M., Andersson, J., Klingegård, M., Lagström, T., Sirkka, A., Fagerlönn, J., Edgren, C., Fredriksson, R., Krupenia, S., et al., 2018. Communicating intent of automated vehicles to pedestrians. Front. Psychol. 9, 1336.

Hoff, K.A., Bashir, M., 2015. Trust in automation: Integrating empirical evidence on factors that influence trust. Hum. Fact. 57, 407–434.

Imbsweiler, J., Stoll, T., Ruesch, M., Baumann, M., Deml, B., 2018. Insight into cooperation processes for traffic scenarios: Modelling with naturalistic decision making. Cogn. Technol. Work 20, 621–635.

Jaguar, L., Rover, 2018. The virtual eyes have it. URL: https://www.jaguarlandrover.com/news/2019/01/jaguar-land-rover-lights-road-ahead-self-driving-vehicles-futur. (Accessed: 31 August 2022).

Kaparias, I., Bell, M.G., Biagioli, T., Bellezza, L., Mount, B., 2015. Behavioural analysis of interactions between pedestrians and vehicles in street designs with elements of shared space. Transp. Res. F 30, 115–127.

Kauffmann, N., Naujoks, F., Winkler, F., Kunde, W., 2017. Learning the "language" of road users-how shall a self-driving car convey its intention to cooperate to other human drivers? In: International Conference on Applied Human Factors and Ergonomics. Springer, pp. 53–63.

Kersten, H., Ruth, H., Ani, K., Martin, K., 2021. What's next for autonomous vehicles? URL: https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/whats-next-for-autonomous-vehicles. (Accessed: 02 February 2022).

Lee, Y.M., Madigan, R., Uzondu, C., Garcia, J., Romano, R., Markkula, G., Merat, N., 2022. Learning to interpret novel ehmi: The effect of vehicle kinematics and ehmi familiarity on pedestrian' crossing behavior. J. Saf. Res. 80, 270–280.

Li, Y., Cheng, H., Zeng, Z., Liu, H., Sester, M., 2021. Autonomous vehicles drive into shared spaces: eHMI design concept focusing on vulnerable road users. In: 2021 IEEE Intelligent Transportation Systems Conference. ITSC, pp. 1729–1736.

Li, Y., Liu, H., Deml, B., 2022. Hmi-based communication methods for negotiation between a manually driven vehicle driver and an autonomous vehicle in an ambiguous traffic scenario. In: 2022 IEEE/SICE International Symposium on System Integration. SII, pp. 244–249.

Liu, H., Hirayama, T., Morale Saiki, L.Y., Murase, H., 2022. Implicit interaction with an autonomous personal mobility vehicle: Relations of pedestrians' gaze behavior with situation awareness and perceived risks. Int. J. Hum.–Comput. Interact. 39 (10), 2016–2032.

Liu, H., Hirayama, T., Watanabe, M., 2021. Importance of instruction for pedestrian-automated driving vehicle interaction with an external human machine interface: Effects on pedestrians' situation awareness, trust, perceived risks and decision making. In: IEEE Intelligent Vehicles Symposium. pp. 748–754.

Mandrick, K., Peysakhovich, V., Rémy, E., Causse, M., 2016. Neural and psychophysiological correlates of human performance under stress and high mental workload. Biol. Psychol. 121, 62–73.

Matthews, M., Chowdhary, G., Kieson, E., 2017. Intent communication between autonomous vehicles and pedestrians. arXiv preprint arXiv:1708.07123.

Merat, N., Louw, T., Madigan, R., Wilbrink, M., Schieben, A., 2018. What externally presented information do VRUs require when interacting with fully automated road transport systems in shared space? Accid. Anal. Prevent. 118, 244–252.

Miller, L., Leitner, J., Kraus, J., Baumann, M., 2022. Implicit intention communication as a design opportunity for automated vehicles: Understanding drivers' interpretation of vehicle trajectory at narrow passages. Accid. Anal. Prev. 173, 106691.

Nissan Motor Corporation, 2015. Nissan IDS concept: Nissan's vision for the future of evs and autonomous driving. URL: https://europe.nissannews.com/en-GB/releases/release-139047. (Accessed: 31 August 2022).

NTHSA, 2020. Automated vehicle for safety. URL: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety#the-topic-benefits. (Accessed: 02 February 2022).

Papakostopoulos, V., Nathanael, D., Portouli, E., Amditis, A., 2021. Effect of external HMI for automated vehicles (AVS) on drivers' ability to infer the AV motion intention: A field experiment. Transp. Res. F 82, 32–42.

Rettenmaier, M., Bengler, K., 2020. Modeling the interaction with automated vehicles in road bottleneck scenarios. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. SAGE Publications Sage CA, Los Angeles, CA., pp. 1615–1619.

Rettenmaier, M., Bengler, K., 2021. The matter of how and when: Comparing explicit and implicit communication strategies of automated vehicles in bottleneck scenarios. IEEE Open J. Intell. Transp. Syst..

Rettenmaier, M., Pietsch, M., Schmidtler, J., Bengler, K., 2019. Passing through the bottleneck-the potential of external human-machine interfaces. In: 2019 IEEE Intelligent Vehicles Symposium. IV, IEEE, pp. 1687–1692.

SAE International, 2021. Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. (J3016_202104).

Schieben, A., Wilbrink, M., Kettwich, C., Madigan, R., Louw, T., Merat, N., 2019. Designing the interaction of automated vehicles with other traffic participants: design considerations based on human needs and expectations. Cogn. Technol. Work 21, 69–85.

Van Der Laan, J.D., Heino, A., De Waard, D., 1997. A simple procedure for the assessment of acceptance of advanced transport telematics. Transp. Res. C 5, 1–10.